

A MOBILE AGENT FRAMEWORK FOR TELECARDIOLOGY

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Abstract - It is generally recognised that telecommunications and the internet in particular are changing the way healthcare is delivered in cardiology. Current implementations of telecardiology are often characterised by a centralised approach. Within this set-up a central system is connected to various remote sites. The central system has to keep track of the activities and of the state of these sites through constant communication with them. This scheme requires large volumes of data, particularly in the case of electrocardiograms (ECGs), to be generated in the remote sites and then to be transmitted to a central control system. This often leads to bottlenecks in communication that may adversely affect the quality of care. In this paper we propose a decentralised approach based on a combination of mobile agents (MA) and an Object Request Broker (ORB) mechanism. Its main aim is to support interoperability and to optimise the monitoring processes by reducing unnecessary communication. MAs possess a degree of autonomy that enables them to filter data on the remote site, and thus ease the load on the central monitoring system. They have the added advantage that they can be customised to meet individual needs. The ORB mechanism is incorporated in order to increase the reliability of MAs and to facilitate the integration of various ECG analysis software systems available on the market. It is expected that the proposed system will provide a framework for improved monitoring of patients and will lead therefore to better healthcare in cardiology.

Keywords - Object Request Broker, telemedicine, telecare, ECG

I. INTRODUCTION

Hospital resources have not always been managed effectively [1]. Telecardiology is one of several promising technologies expected to improve healthcare resource management. Work towards this goal had led to proposals for a central monitoring system to manage patients with artificial pacemakers, and the large number of annual check ups that they require [2]. It is however the recording and analysis of electrocardiography (ECG) data that is attracting most attention. ECG data, together with the patient's medical records, provide important information to the cardiologist enabling the determination of the correct treatment.

One of the applications in telecardiology is to deploy ECG machines in patient homes and local medical centres, and transmit the data generated by them over a network (e.g. Internet) to a central system. Patients with long-term heart

disease, or living in remote areas with difficult access to specialists, rely on telecardiology to provide a better service.

Advances in ECG analysis software [3] have led to improved processes, enabling ECG data to be stored in computers, analysed on site, and the result transmitted at off peak times. It has been suggested that the quality of the ECG analysis software is perhaps better than that of general physicians and is comparable with the review provided by a specialised cardiology service [4]. A number of affordable portable ECG monitoring units have been made available to users and as a result, an increasing number of patients can be expected to make use of telecardiology. The advantages of tele-electrocardiography are faster access to diagnosis, improved quality of care, reduction in hospitalisation costs and better patient management [1]. In all these models, however, large quantities of data need to be transmitted from remote sites to the Central Monitoring System (CMS). This may cause 'bottlenecks' in communication to occur.

In this paper, we propose a framework in which the large volume of ECG data is filtered on site, and only the information required by the consultant is transferred over the Internet. The framework also provides a capability for the co-ordination of the hospital based computer systems involved, thereby ensuring a more effective service.

II. THE SCENARIO

ECG machines and analysis software tools provide important data and information to cardiologists. These tools are not a substitute for doctors but should be considered as a facilitator to telecardiology. Apart from ECG data, cardiologists often require access to other information such as patient's medical records, and data regarding thrombolytic treatment. However, patient records are often located in different database systems [5] on different sites. Furthermore, when needed for consultation, a second cardiologist may not always be present in the hospital. The patients could be at home or in a regional medical centre that has ECG machines. Locating the doctors, transmitting ECG data to the doctor, and searching the related medical information for the patient are essential functions of a cardiology system. The minimum requirement for a telecardiology system is to bring together patients, doctors and hospital in a dynamic and responsive environment.

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A. The Proposed Framework

In the diagram shown in Fig. 1, patients and their monitoring systems, doctors and database systems are connected via the Internet. Within this framework, ECG customised software is migrated from the CMS to the remote PC, on demand, in order to collect and filter ECG data on remote sites. When a patient complains of pains in the chest the remote ECG machine and PC can be used to carry out the acquisition and analysis of the ECG data. The ECG analysis software resident in a PC transforms the data into diagnostic information, and identifies abnormal situations. If a patient presents symptoms that raise the suspicion of acute myocardial infarction, for example, the proposed system generates and sends a notification to the CMS. The ECG data is also transmitted to the CMS and recorded accordingly for the attention of the doctor. The proposed system enables part of the resident software to migrate from the remote PC to the hospital database systems to search for and retrieve the patient's medical records.

A mechanism is provided that makes the CMS aware that a consultant has logged on to the system. The stored ECG data can be displayed on the doctor's PC screen together with the patient's medical records to facilitate the consultant's diagnosis. If the doctor in the hospital needs a second opinion, the proposed system establishes a communication link with other consultants and sends them the required information. The reading from the ECG machine and the transmission of data can be performed in real time, on request, and thus offer an up-to-date picture of the patient's condition. In this way the consultant is provided with specific information for each patient as they are being considered.

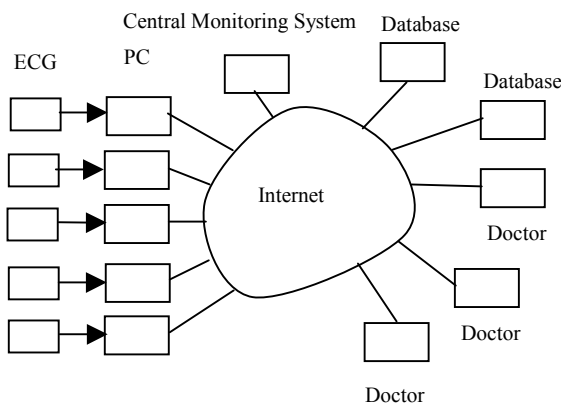


Fig. 1 An internet-based telecardiology system

B. Required Properties

In order to provide an effective solution to the above, the proposed system should possess a number of properties: mobility, observation, system interoperability and ability to filter data at remote sites. Mobility of software is needed in order to allow the software to search for the required information and to display it to the appropriate users over the network. As the system is required to keep track of which user is on or off line and where they are, a global observation mechanism is needed to monitor the status of these entities. It is often the case that software systems in hospitals lack homogeneity and integration. The interoperability of these systems is therefore essential. Furthermore, in order to reduce data transmission, the ECG analysis software needs to be moved to a remote patient's PC. It should also be autonomous and able to determine when to send the crucial information to the CMS which in turn makes it available to the consultant.

III. SOFTWARE ARCHITECTURE

The proposed framework is supported by an object oriented software architecture that incorporates two main components: mobile agents (MA) and an Object Request Broker (ORB) mechanism. Within this environment objects are created, destroyed, and interact with each other. Patients, doctors, and hospital software systems are represented by objects in the proposed system. Thus, each entity can be considered as a proxy with which the CMS is able to communicate.

A. Mobile Agent

An MA is a piece of software that can move from one host to the other over the network to carry out the task that it was designed for. The MA is a delegate of the user who endows it with a certain degree of autonomy required for the realisation of the designated goal. An MA is most likely to be useful in three general cases [6]. The first is when computing systems are subject to disconnection from the network in which case the MA would still operate. The second is when a large amount of data needs to be processed. The MA can be sent large data sources and filter through them locally. The final category of application is the dynamic deployment of software. This particular feature is used to move an MA from the CMS to the remote site and to configure the ECG analysis software imbedded in it to suit the requirements of the remote site. It is also used to migrate the MA from the remote site to search for the patient's records in large databases or to send information to doctors.

B. Object Request Broker

The interoperability in the proposed system is facilitated by the introduction of an ORB mechanism. An ORB is a distributed object technology within a client/server architecture. The first function of the ORB is to enable

different systems to inter-operate in a seamless environment regardless of the programming languages, operating systems, hardware platforms, or locations. This characteristic allows for the integration of various database systems in hospital and diverse ECG analysis software tools. The ORB provides a consistent interface for the participating system by wrapping each software entity in the framework in order to enable their collaboration. The second function of the ORB is to maintain the status of the participating entities in the system (i.e. the deletion and creation of objects) in order to support the MA's operations.

C. Global and Local Observations

In this proposed framework the filtering of data and the reduction of communication requirements are supported by a dual mode of observation that stems from the relationship between the CMS and the MAs, and their respective roles. When a patient needs ECG analysis, the CMS deploys an MA to the requestor. The CMS is responsible for the global observation whilst local observation is performed by the MA.

At the global level the CMS maintains a table of the active objects. Through its observer mechanism the CMS is able to keep the table up-to-date by being set to observe any object creation or deletion that takes place in the observed environment. This updating is essential, since if the environment holds objects of which the CMS is not aware, the logical integrity of any decision making process is flawed. Likewise a lack of knowledge that an object has been deleted would lead to a run time error if the CMS were to attempt to reference such a deleted object.

A general schema for the ORB Observer mechanism is presented in Table I, with its main methods written in an Interface Definition Language (IDL).

TABLE I
AN ORB OBSERVER SCHEMA IN IDL

```
module ORBObserver
{
    interface Observer
    {
        void update(in any observables, in any message);
    };
    interface Observable
    {
        void notifyObserver(in any data);
        void addObserver(in Observer objRef);
        void deleteObserver(in Observer objRef);
        long countObservers();
    };
};
```

When a connection to the CMS is made by any of the objects, the *addObserver* method is called and the remote object reference is stored in the CMS table. References can be made to patients' PCs, doctors or hospital computer systems. In the case of a connection by the patient's PC, the CMS responds by dispatching an MA to the corresponding remote site. The MA is made aware of which patient and data to

monitor and where they are, through the remote object reference obtained from the ORB Observer mechanism. The remote object references also provides the MA with a list of locations of doctors and database systems. When the connection to the CMS is about to terminate the *deleteObserver* method will remove the remote object reference from the table and the CMS will instruct the MA to stop the monitoring activity to prevent any run-time error. The *update* method in the Observer Interface is used by the CMS to inform an MA to withdraw from the remote site.

Under the local mode of observation, the observer mechanism of the MA and the ORB Observer mechanism in the CMS, together with ECG analysis software allow the MA to monitor ECG data. The MA is able to apply its ECG analysis software to analyse and interpret the significance of the patient's conditions. If an abnormal condition is detected in the patient's ECG, the MA will trigger the *notifyObserver* method to notify the CMS. The MA sends the ECG data to the CMS and records it. The MA(s) can then be dispatched to hospital database systems to retrieve the related medical information and locate a doctor. With the knowledge of the observed ECG and related information, the doctor makes a decision as to whether any further treatment is needed (see Fig. 2). The pseudo code given in Table II demonstrates the MA moving between patients, hospital database systems, and cardiologists.

TABLE II
PSEUDO CODE IN A MA

```
If abnormal occurs
Then notify CMS
RemoteObjectReference =
GetObjectReference(CMS)
Agent.MoveTo( RemoteObjectReference of
hospital) and Agent.MoveTo (
RemoteObjectReference of cardiologist)
If Accepted from cardiologist
Then Agent.Display(ECGdata and medicalrecord)
```

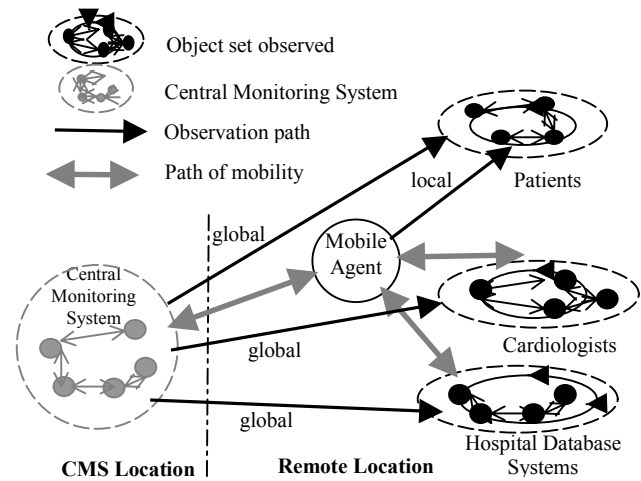


Fig. 2 Global and local observations with MA and ORB

Because the global observation mechanism insures that the CMS is aware of the status of objects in the environment, the system reliability is enhanced. The MA must check the object reference against the corresponding entry in the table held by the CMS. This checking requirement reduces the possibility of unauthorised access. In addition, the security models of the MA and the ORB mechanism are still applicable.

IV. OTHER COMPONENTS

A web browser is used to display the ECG and patient medical records. When the doctor logs onto the computer it will have installed software that will allow him/her to use a browser to view the patient's data. When the consultant wishes to consider a particular patient he will be able to open a folder specific to that patient and the system will maintain the necessary mechanisms for updating the patient's record with the results of his diagnosis and treatment. The complexity of the system is hidden from the doctors who are provided with the necessary resources upon which to apply their expertise. Java and JDBC were used for the implementation of the proposed framework and the integration of various software systems.

V. RELATED WORK

A number of reports show that telecardiology has improved the quality of medical services and reduced the delay of treatment. The TALOS project [7] was designed to link a tertiary cardiac centre with primary care in a remote area of Greece. It was shown that that the provision of telemedicine services was feasible in remote areas. The system saved time and was also cost-effective.

The HYGEIANet is an integrated teleconsultation service in cardiology. The architecture of this project is built upon the WebOnCOLL, a web-based collaboration platform. It introduced XML and workflow to facilitate the interoperability between diverse systems [8].

A web-based approach for ECG monitoring in the home was also proposed in order to optimise patient care strategy [9]. Under this scheme, an intelligent agent is used to retrieve the new ECG data sent from the patient. The agent also automatically analyses clinical data to provide an optional summary report along with suggestions for treatment for the doctor and patients. A similar approach using the web for monitoring real-time ECG data is presented in [10].

In contrast to these models, our approach promotes and supports a dynamic environment.

VI. CONCLUSIONS AND FUTURE WORK

The main contribution of this work is the introduction of an MA and ORB mechanism to support the acquisition and filtering of ECG data at a remote site, and the co-ordination of hospital resources in a heterogeneous environment. This is a useful framework with a potentially wide range of applications. We have already proposed a similar framework for a complex engineering design environment. Early results suggest that this approach is very promising and offers more benefits than traditional systems [11,12].

An implementation of a simple model using the mechanisms described has already been carried out within our labs. A test bed will be set up in the department to examine the results from the proposed system. An ECG simulation tool [13] developed in the department will be installed on over 100 PCs in the labs. A random mechanism will be injected into the ECG simulator to simulate a number of patients with varying heart conditions. This will enable us to measure the performance and quality of the proposed system.

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